I2C Functional Description

Applicable to following sensors
SFM3000, SFM3200, SFM3300, SFM3400
I2C details for other SFM sensors are directly included in the sensor's datasheet

Key content

- I2C communication details
- Command set and data transfer sequences
- Reset, limitations and extended command sets

Summary
This document describes the I2C communication with the SFM3xxx sensor series. Communication between the master and the SFM3xxx series sensor runs via the digital I2C-interface. This document contains all essential as well as several extended commands and some basic descriptions of the SFM3xxx series I2C protocol. For the detailed specifications please check the NXP document "The I2C-Bus Specification".

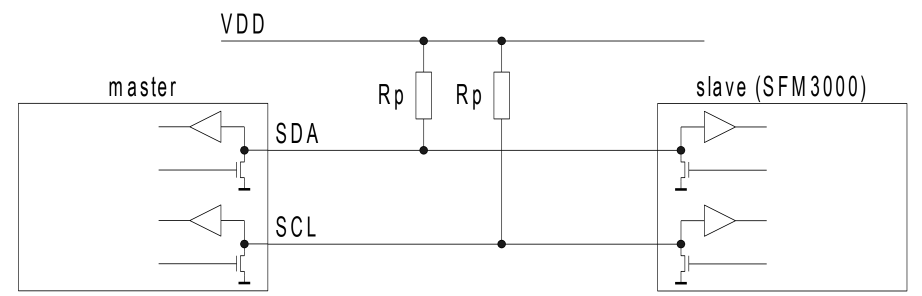
1 Interface connection

Bi-directional bus lines are implemented by the devices (master and slave) using open-drain output stages and a pull-up resistor (Rp) connected to the positive supply voltage.

The recommended pull-up resistor value depends on the system setup, particularly on the capacitance of the circuit or cable and bus clock frequency. For quick prototyping a value of 10kOhm is a reasonable choice. Please refer to NXP's I2C bus specification in order to determine the optimal value.

The capacitive loads on SDA and SCL line have to be the same. It is important to avoid asymmetric capacitive loads. In case of long wires (>10cm) it is necessary to shield SDA and SCL. Wires longer than 30cm should not be used.

I^{2}C Connection Diagram



Both bus lines, SDA and SCL, are bi-directional and require an external pull-up resistor.

2 I2C Address

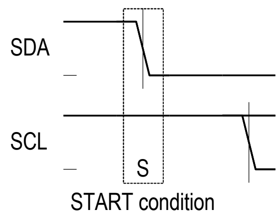
The I2C address is represented by a 7-digit binary value. By default, the I2C address is set to 64 (1000000b). The address is always followed by a write bit (0) or read bit (1). The default hexadecimal I2C header for read access to the sensor is therefore 0x81.

3 I2C communication

The I2C protocol consists of start and stop conditions at the beginning and ending of the transfers and a number of 8 bit frames in between, of which each frame is acknowledged in case of a successful transmission.

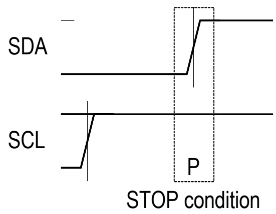
3.1 Transmission START Condition (S)

The START condition is a unique situation on the bus created by the master, indicating to the slaves the beginning of a transmission sequence (the bus is considered busy after a START).

I^{2}C Transmission Start Condition

A HIGH to LOW transition on the SDA line while SCL is HIGH

3.2 Transmission STOP Condition (P)

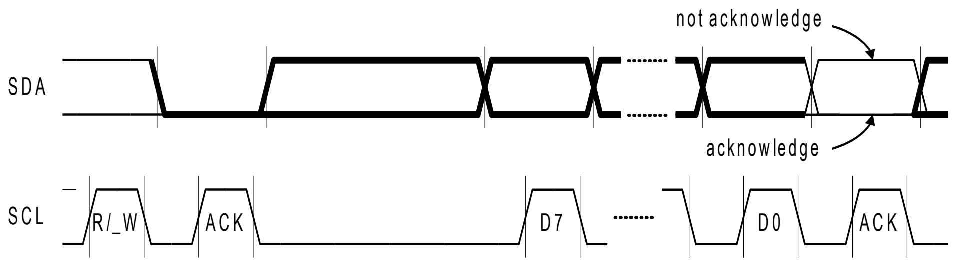
The STOP condition is a unique situation on the bus created by the master, indicating to the slaves the end of a transmission sequence (the bus is considered free after a STOP).

I^{2}C Transmission Stop Condition

A LOW to HIGH transition on the SDA line while SCL is HIGH.

3.3 Acknowledge (ACK) / Not Acknowledge (NACK)

Each byte transmitted over the I2C bus is followed by an acknowledge condition from the receiver. This means that after the master pulls SCL low to complete the transmission of the 8th bit, SDA will be pulled low by the receiver during the 9th bit time. If after transmission of the 8th bit the receiver does not pull the SDA line low, this is considered to be a NACK condition.

I²C Acknowledge / Not Acknowledge



Each byte is followed by an acknowledge or a not acknowledge, generated by the receiver (The bold lines indicate that the sensor controls the SDA line)

3.4 Data transfer format

Data is transferred in byte packets in the I2C protocol. Each byte is followed by an acknowledge bit. Data is transferred with the most significant bit first.

A data transfer sequence is initiated by the master generating the Start condition (S) and sending a header byte. The I2C header consists of the 7-bit I2C device address and the data direction bit (R/_W).

The value of the R/_W bit in the header determines the data direction for the rest of the data transfer sequence. If R/_W = 0 (WRITE) the direction remains master-to-slave, while if R/_W = 1 (READ) the direction changes to slave-to-master after the header byte.

4 Command Set and Data Transfer Sequences

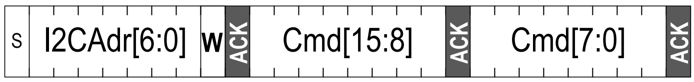
After a data transfer is initiated by a header byte with a Write, a command is send to the slave. A command is represented by a 16-bit command code, consisting of two 8-bit frames. The data direction may not change after the command bytes, since the R/_W bit of the preceding I2C header has already determined the direction to be master-to-slave. In order to execute Read commands, the following principle is used. On successful (acknowledged) receipt of the command code, the sensor stores the command internally. A successive Read is invoked by initiating an I2C data transfer sequence with R/_W = 1 and the sensor replying with the requested information.

If a correctly addressed sensor recognizes a valid command and access to this command is granted, it responds by pulling down the SDA line during the subsequent SCL pulse for the acknowledge signal (ACK). Otherwise it leaves the SDA line unasserted (NACK).

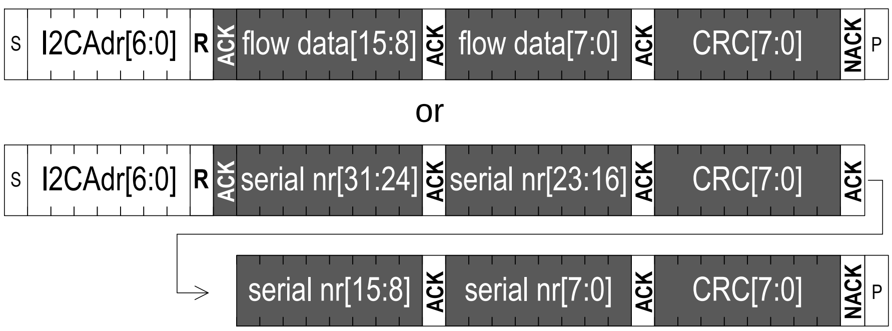
The commands are described below, and the data transfer sequences are specified.

Command [16 bit]	*Number of bytes to read back*	*Command Description*	*Comment*
0x1000	2	Start continuous measurement and/or move internal pointer (back) to flow measurement result register	See chapter 4.1
0x31AE	4	Read Serial Number (bit 31:0)	See chapter 4.2
0x2000	NA	Soft reset command	See chapter 6

I²C master writes command to SFM3000 with address I2CAdr



I²C master reads command results from SFM3000 with address I2CAdr



Dark areas with white text indicate that the sensor controls the SDA (Data) line.

4.1 Measurement Triggering

Flow measurements are started by writing the start measurement command (0x1000) to the sensor. Measurement results are continuously updated until the measurement mode is stopped by sending any other command or by a sensor reset. After a start measurement command, the measurement results can be read out continuously[1]. In the case that the sensor chip performs an unexpected reset, e.g. due to an intermediate drop in the supply voltage below 4.75V, the sensor chip will stop measuring and a sensor read command will provide an invalid result from a user register. To avoid such an invalid result it is recommended to repeat the “start measurement” command in a repeated interval or for each “read” command as shown in the tables below. The measurement result register is set to invalid after being read and only set to valid again when a new measurement result is available. If no valid result is available, the chip does not acknowledge a read command.

The tables below give an example sequence with explanations for every command.

Timing for SFM3000 (see below table for other SFM3xxx)			
∆ time (ms)	*I²C communication*	*Measuring?*	*Comment*
0	-	No	Powering up of the sensor (heater powered up with start up of the sensor SFM3000)
100	80a 10a 00a	→ Yes	After the sensor is out of reset, the start measurement command is sent
0.5	81n FFa FFa FFn	Yes	First measurement result read out after chip reset is invalid
	80a 10a 00a	Yes	Start measurement command is sent
0.5	81a F0a 00a CRCn	Yes	Valid measurement data is read out + CRC byte.
	80a 10a 00a		Start measurement command is sent
0.5	81a F0a 14n	Yes	Updated flow value is read out. CRC is not read out.
	80a 10a 00a		Start measurement command is sent
0.4	81n	Yes	No valid measurement data is ready yet. The read request is not acknowledged
0.1	81a F0a 28a CRCn	Yes	New measurement data is available and read out.
1	80a 31a AEa	→ No	Send read serial number command
0.2	81a 5Aa D8a CRCa 47a 40a CRCn	No	Read example serial number
0.3	80a 10a 00a	→ Yes	Start measurement command is sent
0.5	81a F0a 00a CRCn	Yes	Measurement data is read out + CRC byte.
	80a 10a 00a		Start measurement command is sent
0.5	81a F0a 00a CRCn	Yes	Measurement data is read out + CRC byte.
	80a 10a 00a		Start measurement command is sent
Dark areas with white text indicate that the sensor controls the SDA (Data) line. An a indicates and ACK, an n indicates a NACK			

[1] This means that an I2C header with R/_W bit = 1 could be sent continuously to read out those results, without preceding it with command 0x1000

Timing for SFM3200, SFM3300 and SFM3400			
Δ time (ms)	*I²C communication*	*Measuring?*	*Comment*
0	-	No	Powering up of the sensor
40	80a 10a 00a	No	After the sensor is out of reset, the start measurement command is sent (unlike for SFM3000, the heater is only started with the start measurement command)
100	81n FFa FFa FFn	Yes	First measurement result read out after chip reset is invalid
	80a 10a 00a	Yes	Start measurement command is sent
0.5	81a F0a 00a CRCn	Yes	Valid measurement data is read out + CRC byte.
	80a 10a 00a	Yes	Start measurement command is sent
0.5	81a F0a 14n	Yes	Updated flow value is read out. CRC is not read out.
	80a 10a 00a	Yes	Start measurement command is sent
0.4	81n	Yes	No valid measurement data is ready yet. The read request is not acknowledged
0.1	81a F0a 28a CRCn	Yes	New measurement data is available and read out.
1	80a 31a AEa	→ No	Send read serial number command
0.2	81a 5Aa D8a CRCa 47a 40a CRCn	No	Read example serial number
0.3	80a 10a 00a	→ Yes	Start measurement command is sent
0.5	81a F0a 00a CRCn	Yes	Measurement data is read out + CRC byte.
	80a 10a 00a	Yes	Start measurement command is sent
0.5	81a F0a 00a CRCn	Yes	Valid measurement data is read out + CRC byte.
	80a 10a 00a	Yes	Start measurement command is sent
Dark areas with white text indicate that the sensor controls the SDA (Data) line. An `a` indicates and ACK, an `n` indicates a NACK			

4.2 Read Data Layout

Data that is read back from the Sensor consists of two or four bytes, with the most significant byte and bit read first. The least significant bit and byte are read last. The following maps give more details on the content of the different results:

Read flow measurement result

Bit	*#Bits*	*Description/Coding*
15:0	16	Flow measurement result. Bit <1:0> is always zero.

Read serial number

Command	*#Bits*	*Description/Coding*
0x31AE	32	Bit 31:0 of the unique serial number

4.3 Converting measurement result to measured values

In order to obtain the measured flow in the predefined unit, the flow measurement result needs to be converted according to the following formula:

$$flow\ [\mathrm{slm}] = \frac{measured\ value - offset\ flow}{scale\ factor\ flow}$$

Offset and scale factor can be found in the product datasheet.
Please note that the first measurement performed directly after chip initialization might not be valid.

5 CRC-8 Redundant Data Transmission

Cyclic redundancy checking (CRC) is a popular technique used for error detection in data transmission. The transmitter appends an n-bit checksum to the actual data sequence. The checksum holds redundant information about the data sequence and allows the receiver to detect transmission errors. The computed checksum can be regarded as the remainder of a polynomial division, where the dividend is the binary polynomial defined by the data sequence and the divisor is a "generator polynomial".

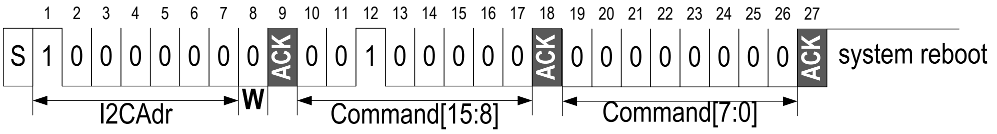
The SFM3000 sensor implements the CRC-8 standard based on the generator polynomial: $x^8 + x^5 + x^4 + 1$. (0x31)

Note that CRC is only used for data transmitted from the slave to the master.

For details regarding cyclic redundancy checking, please refer to the AppNote SFM-04 "CRC Checksum" on our website and the relevant literature.

6 Soft reset

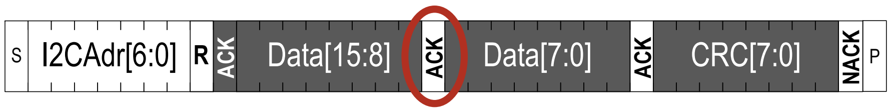
The soft reset command forces a sensor reset without switching the power off and on again. On receipt of this command, the sensor reinitializes the control/status register contents from the non-volatile memory and starts operating according to these settings.

I²C Soft Reset
16 bit command code: ***0x2000*** Command: **Soft Reset**


7 Limitations

The I²C interface of the SFM3xxxx show deviations from the NXP I²C specification and might lock up and cease to react (including to the soft reset command), under the following conditions:

- Glitches on the SCL, for example caused by electromagnetic irradiation or coupling.
- The master does not acknowledge the first byte read from the sensor after having sent the header byte (I2C address + R bit). The critical acknowledge bit is highlighted below.

I²C read sequence. ACK after first read byte highlighted.

Dark areas with white text indicate that the sensor controls the SDA (Data) line.

The following design precautions are recommended to reduce the probability of sensor freeze/lockup and to restore the sensor operation with a power (hard) reset in the event of a freeze:

- The cable length from the sensor to the microprocessor is recommended to be as short as possible and not longer than 30 cm as well as shielded. For wires longer than 10 cm the SDA and SCL must be shielded. Sources that emit electromagnetic radiation must be kept away from the I2C connection.
- When data is read from the sensor, one must ensure that the first data byte of the transaction is always acknowledged by the master.
- It must be possible to reset the sensor through a hard reset in case the sensor freezes by powering the supply voltage of the sensor off and on again.

Suggested measures and error handling logic to establish a reliable communication and read-out of the measurement values:

- Send the "Start measurement" command before every read command to avoid an unnoticed sensor reset.
- Ensure the sensor acknowledges all commands, and the CRC checksum of the measurement data is valid.
- In case of an unexpected behavior from the sensor (NACK or a wrong CRC checksum), use the last valid flow value and perform a sensor power (hard) reset if the error persists for 5 (or any other application specific error threshold) consecutive cycles.

8 Extended Command Set

Task	*Command [16 bit]*	*# of bytes to read back*	*Detailled Command Description*
Start flow measurement	0x1000	2	Start continuous flow measurement
Start temperature measurement*	0x1001	2	Start continuous temperature measurement. Bit <1:0> are always zero.
Read scale factor	0x30DE	2	Combining both bytes yields the flow scale factor
Read offset	0x30DF	2	Combining both bytes yields the flow offset
Read article number	0x31E3	2	In order to read out the product type/article number, two commands have to be sent to the sensor resulting in 4 bytes of data (bits <31:0>). The command 0x31E3 results in the first two bytes (bits <31:16>) followed by command 0x31E4 with another two bytes (bits <15:0>).
	0x31E4	2	
Read serial number	0x31AE	2	In order to read out the serial number, two commands have to be sent to the sensor resulting in 4 bytes of data (bits <31:0>). The command 0x31AE results in the first two bytes (bits <31:16>) followed by command 0x31AF with another two bytes (bits <15:0>).
	0x31AF	2	
Soft reset	0x2000	NA	Soft reset command

SFM3xxx-AW versions only! There is an additional EEPROM on the SFM3300-AW and SFM3400-AW to allow storage of customer-specific data (e.g. usage hours). Please see all details in the datasheet of the EEPROM. The EEPROM is of type 24LC01BT-I/MC. No additional validation or modification of EEPROM settings has been performed by Sensirion.

*Allows read out of the chip temperature. Please note that the sensor temperature does not necessarily reflect the temperature of the gas flowing through the sensor. See additional AppNote SFM-08 “Temperature Effects”.

9 Revision history

Date	Author	Version	Changes
July 2013	ANB	1	First release
July 2015	ANB	1.1	Added Read Serial Number Command. Minor changes.
Jan 2021	PSIM	1.2	Added Extended I2C Command Set and applicability to further SFM3x00 sensors
May 2022	LOEH	1.3	Detailed measurement mode (section 4.1) and measures to establish reliable communication despite the I2C limitations (section 7)

10 Headquarters and Subsidiaries

SENSIRION AG
Laubisruetistr. 50
CH-8712 Staefa ZH
Switzerland
phone: +41 44 306 40 00
fax: +41 44 306 40 30
info@sensirion.com
www.sensirion.com

Sensirion Inc., USA
phone: +1 805 409 4900
info_us@sensirion.com
www.sensirion.com

Sensirion Japan Co. Ltd.
phone: +81 3 3444 4940
info@sensirion.co.jp
www.sensirion.co.jp

Sensirion Korea Co. Ltd.
phone: +82 31 337 7700 3
info@sensirion.co.kr
www.sensirion.co.kr

Sensirion China Co. Ltd.
phone: +86 755 8252 1501
info@sensirion.com.cn
www.sensirion.com.cn

Sensirion AG (Germany)
phone: +41 44 927 11 66
info@sensirion.com
www.sensirion.com

To find your local representative, please visit www.sensirion.com/contact